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Impact of Variation in Monsoonal Rainfall and Temperature on Paddy Production and its Adaptive Strategies: A Case Study from Bhaktapur District of Nepal

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Abstract

This study was carried out to assess the impact of climate change on paddy yield in Bhaktapur, Nepal. The study compared the summer rainfall variability, summer temperature variability, and farmers' perception of rainfall and temperature changes over a 30-year period. A household survey of 420 houses was conducted to collect information supplemented by meteorological data from the Department of Hydrology and Meteorology (DoHM). Following this, significant increases and decreases in temperature and rainfall were observed on annual and seasonal time scales, respectively. The obtained result shows the annual precipitation trend of the study area is increasing at a rate of 0.24 mm yr^{-1}. The linear trend analysis of the pre-monsoon indicates that the rainfall is increasing at the rate of 0.18 mm yr^{-1} and the monsoon shows the rainfall is increasing at the rate of 0.57 mm yr^{-1}, whereas the post-monsoon rainfall is decreasing at the rate of 0.02 mm yr^{-1}. The biggest changes in precipitation were observed during the monsoon season. The monsoon precipitation trend in the time series was found to be increasing at a rate of 0.57 mm yr^{-1}. This variation in monsoon rainfall is clearly unfavorable for the agriculture system of the study area. When these recent changes in the temperature and precipitation were compared over 30-year time series data from the weather station, it is apparent that the climate of the study area exhibits fluctuation over time, many of the changes being very erratic. As per the data, all kinds of temperatures are being increased annually. According to the linear trend shown below, average annual temperature, minimum temperature, and maximum temperature are increasing at rates of 0.038°C yr^{-1}, 0.054°C yr^{-1}, and 0.021°C yr^{-1}, respectively. The results show that future climate change in Nepal, including higher temperatures and erratic rainfall, might have a negative impact on paddy productivity and yield in the study area.

Keywords

Monsoon; Precipitation; Paddy; Temperature; Yield

Introduction

Climate change is described as "a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere (Field and Barros, 2014). The World Meteorological Organization (WMO) defines climate variability as variations in the mean state and other statistics of the dominant climatic variables on temporal and spatial scales outside the normal weather. When compared to long-term statistics of the relevant climatic variables, they are used to indicate changes in climatic variables over a specific time period (Carrer and Urbinati, 2006). Global temperature, precipitation, and carbon emissions cause the climate to fluctuate throughout time, which has a substantial impact on agricultural development and production (Chandio *et al*., 2021; Klutse *et al*., 2021). The warming trend observed in Nepal is greater than the average for the world. The trends of annual and seasonal maximum temperature in Nepal are both considerably positive at 99.9% confidence level. The trend in the annual maximum temperature is 0.056°C yr^{-1}. The pre-monsoon season has the lowest positive trend (0.051°C yr^{-1}), while the monsoon season has the highest positive trend (0.058°C yr^{-1}). The maximum temperature in Nepal has been increasing both seasonally and annually, with inter-annual variability in every season (Panthi *et al*., 2015). Annually and during the monsoon season, the trend of Nepal's average minimum temperature shows an upward tendency. However, only the monsoon trend is significant at 95% confidence level. The minimum temperature tends to drop during the other seasons, but at 95% confidence level, these trends are negligible (Ghimire, 2019). Similarly, regarding the trend of precipitation, the seasonal and annual precipitation patterns in Nepal show decreasing precipitation in all seasons, with the post-monsoon season having the steepest declining trend (-0.3 mm yr^{-1}). In Nepal, the annual decline in precipitation is 1.3 mm yr^{-1}. However, none of the declining tendencies is significant (Ghimire, 2019). Paddy accounts for the largest percentage of farmland (42.2%) under it and output (51.7%%) in Nepal (MoAC, 2017). The major source of employment, GDP, and raw materials supplied to active agro-based businesses comes from rice farming. However, these contributions have been falling over time. For instance, the Central Bureau of Statistics of Nepal (CBS) reported in 2013 that the area under paddy cultivation had shrunk by more than 129,000 hectares. Bhandari, Sanjel and Adhikari (2017) reported that the proportion of households engaged in paddy cultivation had dropped from 76 percent in 1996 to 72.3 percent in 2011. One of the major issues of this century is climate change (CC), which severely impairs the way of life of rural residents who rely primarily on agriculture for their food (Ali and Erenstein, 2017; Pickson, He and Boateng, 2021). They engage in unsustainable agricultural production methods (Rohila *et al*., 2017), which contribute to the generation of approximately 10% of the world's carbon dioxide (CO_2) and harm agricultural productivity in poor nations (Mulungu *et al*., 2021; Pickson, He and Boateng, 2021). It is now obvious that human activities like the combustion of fossil fuels and deforestation are the main causes of climate change. As a result, current anthropogenic greenhouse gas emissions are at their highest level (Howarth, 2014). Both natural systems and people are affected by rising temperatures and heavy or no rain (Easterling *et al*., 2000). Water supplies are impacted, which has an impact on agriculture and may have long-term repercussions on food security (Malla, 2008). Nepal is one of many developing countries with an agriculture-dominated economy (Amgain, 2021). A major portion of agriculture's production and the calorie requirements of the people are supplied by rice (Ray *et al*., 2013). On the other hand, Nepal experiences a wide range of climatic variation within different regions with different altitudes, covering a wide range of climatic scenarios. Therefore, a study of the effects of climate variation might enlighten the different circumstances of climate and its effect on paddy production.

Around 90% of the world's paddy cultivation and production occurs in Asia alone (Rani *et al*., 2014). It is the primary source of food for 158 million Bangladeshis (Chowdhury and Khan, 2015); it covers one-third of all arable land in India (Farook and Kannan, 2016); it is the second largest crop in Pakistan (Rehman *et al*., 2015); and it is the primary source of food in Bhutan (Katwal *et al.*, 2015), Nepal (Devkota, Phuyal and Shrestha, 2018), and Sri Lanka (Thirumarpan, 2014). For this reason, the production of rice is being threatened by climate variations, including excessive or insufficient rainfall, extremely high or low temperatures, and poor soil quality. The effect of climate change on cereal crop yields at the regional and national levels has been quantified in a few studies (Wang *et al*., 2018; Aryal *et al*., 2020; Habib-ur-Rahman *et al*., 2022). For instance, Lal (2007) estimated that South Asia's wheat crop yield would decline by 4–10% by the year 2100. Contrary to this, Shrestha, Thin and Deb (2014) reported that future climate conditions would improve the rice yield and hence would increase the food security in the region, based on a study in Myanmar. The impact of climate change on Nepal's agricultural gross domestic product was calculated by Acharya and Bhatta (2013) using a quantitative modeling approach. They discovered a favorable influence because of anticipated increases in precipitation. Based on an analysis of 20 of Nepal's most important rice-growing districts, Karn (2014) estimated a 4.2% decline in rice yield. In a study based on a model conducted by Palazzoli *et al*. (2015) in the Indrawati river basin of central Nepal, varied estimations of agricultural production changes were discovered using various future climate prediction data (-36% to +18% for wheat and -17% to +12% for rice). Significant obstacles also exist for "modest but good moves" by business and public players at lower levels of government, while successful global collective action towards climate mitigation remains elusive (Ostrom, 2012).

Nevertheless, there is little research that measures how climate change affects agricultural households' livelihoods in Nepal (Eriksson *et al*., 2009; Kunwar and Bohara, 2017). The fact that the majority (50.67%) of Nepalese households have not ever heard of climate change being a good indicator, because of the absence of pertinent studies (CBS, 2017). Because of this ignorance, sensible policymaking at the municipal or regional levels faces significant obstacles, and private players are unable to implement long-term adaptation plans. Secondly, despite the fact that there is evidence that some households have adapted to climate change (Chhetri *et al*., 2012; Gentle and Maraseni, 2012), it is still unknown how extensive and what kind of trade-offs were made during adaptation, as well as what new vulnerabilities were created as a result. Thus, it is clear that peri-urban areas like Bhaktapur district have not been the subject of much research.

Nepal's agriculture is at subsistence level and heavily reliant on the monsoon rainfalls. The meteorological conditions of the year have a substantial impact on monsoon impacting agriculture's production for the entire year and its contribution to the GDP. According to Nepal's Economic Survey, the agriculture sector is impacted by both favorable and unfavorable meteorological circumstances, which cause GDP to fluctuate and hinder overall economic growth (MOF, 2014). Hence, the influence of the climatic variables on the agriculture sector is one of the important topics to study. This study aimed to determine the current status of paddy production and climate change impacts on paddy production in the proposed study area. This study also helped to understand the relevance of adaptive measures taken by the locals.

Materials and Methods

Study Area

Bhaktapur, locally called Khowpa, is a city in the East corner of the Kathmandu valley in Nepal, located about 13 km from the capital city, Kathmandu (Figure 1). In terms of area, Bhaktapur is the smallest district in Nepal. Geographically, it is located on a small hill in the Eastern part of the Kathmandu valley. The total area of Bhaktapur district is 6.889 km^2. It is located between 27°40′20″N and 85°25′40″E. The population density of Bhaktapur district is 11,000/km^2. As part of the Kathmandu valley, it shares its history, culture, and language with the other cities of the valley. Bhaktapur is one of the most visited tourist destinations in Nepal. As such, it is an important tourist destination in Nepal, with the medieval city attracting 301,012 tourists in 2014. Bhaktapur's potters and handicraft industries are also known nationwide.

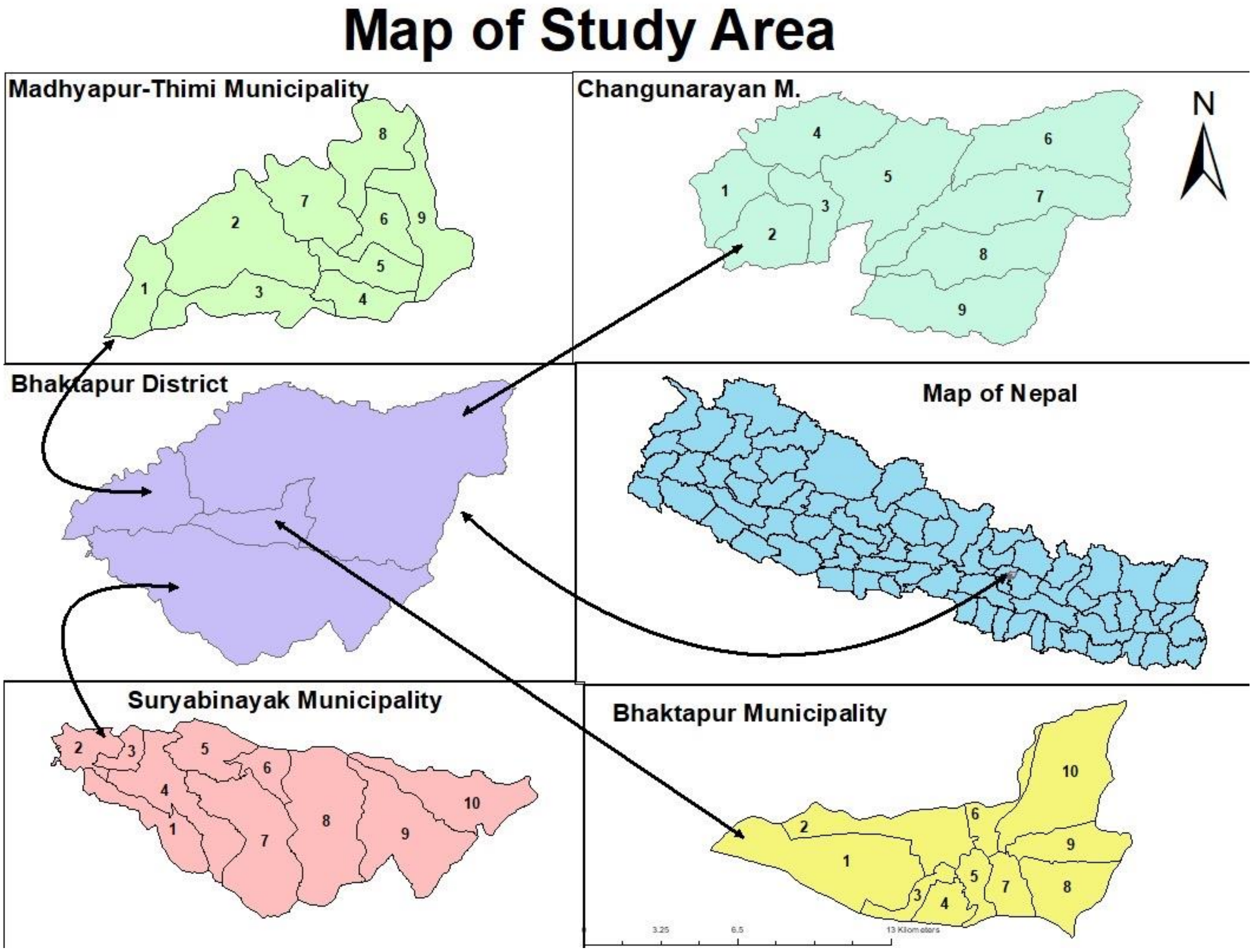

Figure 1: Map of the Study Area

Data Collection

The research was carried out in Bhaktapur District. Both qualitative and quantitative methods were employed to collect data from the study sites.

Primary data collection

A preliminary field visit was conducted in order to determine the status of the proposed area. The methods that were used during the data collection included household surveys, focus group discussions (FGDs), and direct observation. Secondary information on the rainfall, temperature, and paddy production data for specific periods of the study sites was collected from the relevant agency. Most of the information was collected through a household survey using a structured questionnaire. In order to gain common information, FGD was carried out.

A. Sample Size

The sample size generally depends on the variability in the study population and the sampling techniques. In this study, the statistically valid sample size was derived using the equation given by Arkin and Colton (1963). Using the technique given by Arkin and Colton (1963), the number of households has been identified and the necessary information was collected from the respondents.

$n = NZ^2P(1-P)/Nd^2+Z^2P(1-P)$

where,

n= sample size
N= total number of study population/households
Z= the value of normal variable, at 95% confidence level (1.96)
P= the highest possible proportion of population (0.05)
D= maximum acceptance error (0.05)

B. Questionnaire Survey

In this method, a structured questionnaire was developed to acquire information from the respondents in order to fulfill the objectives. The questionnaire had two sections. The first section focused on the general information of the respondents, such as age, sex, education, occupation, family size, and family structure, whereas the second section focused on parameters related to climate change.

C. Focus Group Discussion (FGD)

A small, homogeneous group of experienced respondents gathered together to discuss; a qualitative study was referred to as FGD Researchers extensively use this exploratory method to generate qualitative data and triangular findings (Morgan, 1997). This method was used with the respondents from all of the municipalities in the Bhaktapur district, as well as some local residents to learn about people's perceptions of rainfall variation, temperature, and adaptation strategies.

D. Key Informant Survey

This method was more helpful in getting the information that was missed in the FGDs. This method has provided better and in-depth information about the proposed study area. The government staff and local elderly people were considered as informants. It was attempted to obtain information such as trends in precipitation patterns, temperature variation, and the effects of climate change on rice production.

Secondary Data Collection

Secondary data was collected from different journals, books, published and unpublished reports, articles, and websites. Also, data was collected from different governmental departments in Nepal. Rainfall and temperature data were collected from the Department of Hydrology and Meteorology (DHM) of the study area. The data for paddy was collected by the Ministry of Agricultural Development (MoAD).

Data Analysis

The data collected from different methods was checked and tabulated. Tabulated data was analyzed using MS-EXCEL and SPSS. All the necessary statistical tools like tables, graphs, means, and medians were calculated using this software. Statistical analysis was performed to analyze the collected quantitative data.

Results

This study addressed research questions such as the effects of temperature and rainfall on paddy productivity, the relationship between temperature and paddy productivity, the rainfall trend, and the people's adopted adaptive strategies. The details of the results are presented below.

Socio-Economic and Demographic Characteristics

A sample of 420 respondents was taken from the total population of Bhaktapur district, i.e., 5, 8, 9 wards in Changunarayan municipality, 10, 1, 2 wards in Bhaktapur municipality; 1, 2, 3, 9 wards in Madhyapur Thimi municipality; and 1, 4, 7, 10 wards in Suryabinayak municipality. Since there is a greater agricultural land and more farmers stay in these wards, they were selected and were interviewed for purpose of survey.

Age group of respondents

Sixty-seven percent of the respondents were males, and the remaining 33 percent were females. Respondents were categorized by their age groups. 50% of the respondents belonged to the age group 20–40, 46% of the respondents belonged to the age group 40–60, and 4% belonged to the age group above 60.

Education level of respondents

Respondents' education status was identified as illiterate, literate, lower secondary, higher secondary and university level. Most of the respondents were literate (43%) in the study area followed by illiterate (29%), while 12% of them received lower secondary education and 12% received higher secondary education. Only 3% of the respondents went to a university.

Main income sources

Agriculture was the main occupation for the majority of the households. Most of the households are totally dependent on the agriculture in the study area. Besides, agriculture, services and labor contributed as the primary source of family income to 45% and 25% and 5%, respectively. Therefore, there is a higher number of households with multiple sources of incomes. The business and job abroad were told by 8% and 15%, respectively, in the study area.

Local Rainfall and Temperature Scenario

As per the data, all types of temperatures have increased annually. The linear trend shows that average annual temperature, minimum temperature, and maximum temperature are increasing at the rate of 0.038°C yr^{-1}, 0.054°C yr^{-1} and 0.021°C yr^{-1}, respectively (Figure 2). The average temperature was highest in the year 2010 with the value of 20.24°C. Strong signals of climate change were detected when the weather station data near Bhaktapur district was examined over the recent history of 30 years (1990-2021). In 1996, minimum temperature seems to have decreased indicating that there was cold winter. Similarly, there was an increase in the maximum temperature indicating that the summer was too hot. Similarly, in 1997, both the maximum and minimum temperatures were decreased as a result of which the year seemed to have experienced cold.

The trend of annual precipitation in the study area is increasing at the rate of 0.24 mm yr^{-1} (Figure 3). The linear trend analysis of pre-monsoon time shows that the rainfall is increasing at the rate of 0.18 mm yr^{-1} (Figure 4) and of the monsoon shows that the rainfall is increasing at the rate of 0.57 mm yr^{-1} (Figure 5), whereas of the post-monsoon indicates that it is decreasing at the rate of 0.02 mm yr^{-1} (Figure 6). The biggest changes in precipitation were observed during the monsoon season. A trend of monsoon precipitation in the time series was found to be increasing at the rate of 0.57 mm yr^{-1}. The maximum rainfall occurred during monsoon was 1461.2 mm in the year 1999 followed by 1,454.2 mm in the year 2003. There has been a very erratic trend of monsoon precipitation ranging from 200 mm to just below 500 mm. This variation in monsoon rainfall is clearly unfavorable for the agriculture system of the study area. When these recent change in the temperature and precipitation was compared over 30-year time series data obtained from the weather station, it is seen that the climate of the study area exhibits fluctuation over time, many of the changes are very erratic.

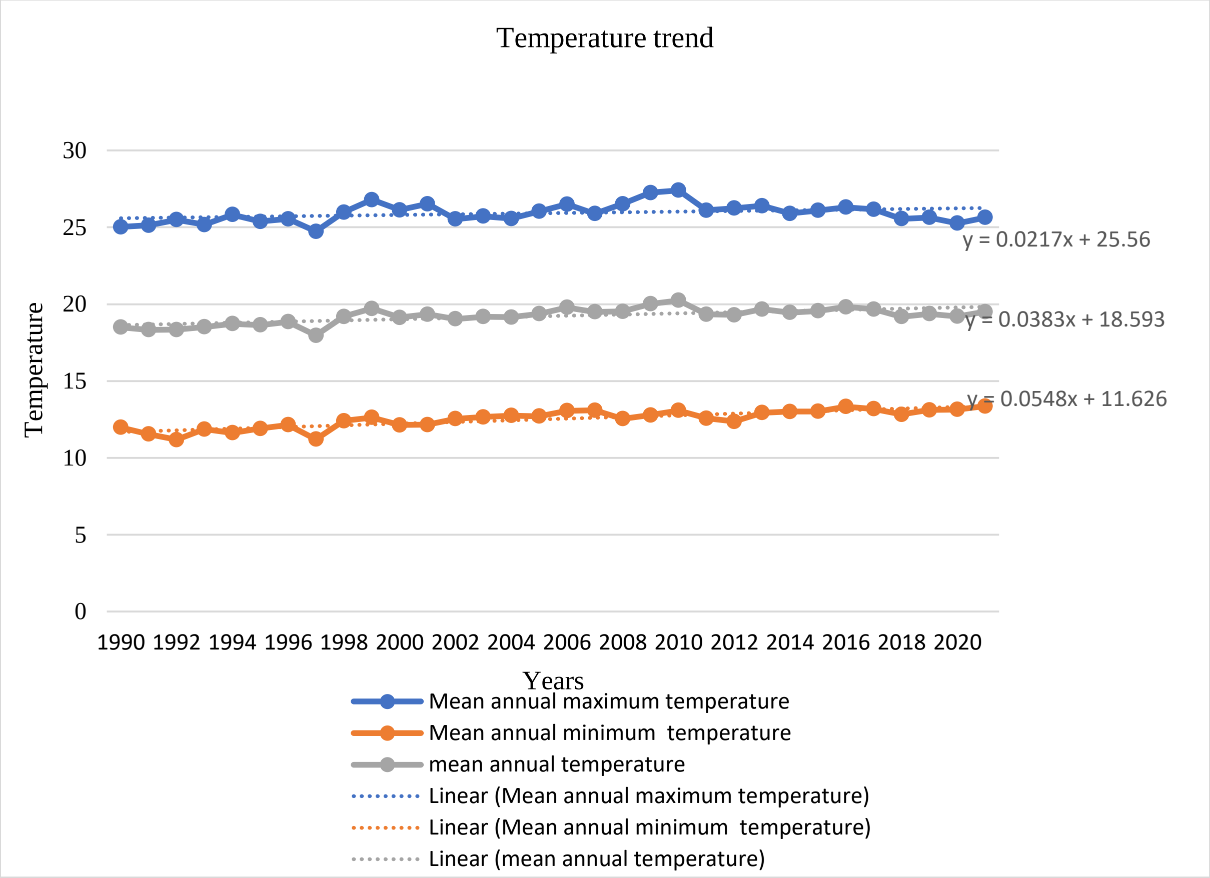

Figure 2: Temperature trend of Kathmandu Airport

Figure 3 shows the increasing trend of annual rainfall at the rate of 0.24 mm year. The maximum annual rainfall was in the year 2013, followed by 2002, and minimum annual rainfall was in the year 1991, followed by 1992.

The pre-monsoon rainfall has significantly increased annually at the rate of 0.18 mm yr^{-1} (Figure 4). The significantly highest pre-monsoon rainfall was experienced in the year 1998 and the least pre-monsoon rainfall was experienced in the year 1999. The trend of pre-monsoon rainfall shows significant increase. This gives positive result in total annual rainfall, but negative impacts on harvesting of crops grown before paddy. Late or early harvesting of crops may shift the crop calendar, as a result.

The maximum monsoonal rainfall was experienced in the year 1999 and the least monsoonal rainfall was experienced in the year 1991 (Figure 5). The trend line shows the increasing trend of monsoon rainfall at the rate of 0.57 mm yr^{-1}.

Figure 6 shows the trend of post-monsoon rainfall decreasing significantly at the rate of 0.022 mm yr^{-1} annually. The highest annual post-monsoon was experienced in the year 2004 and least post-monsoon rainfall was experienced in the year 2000.

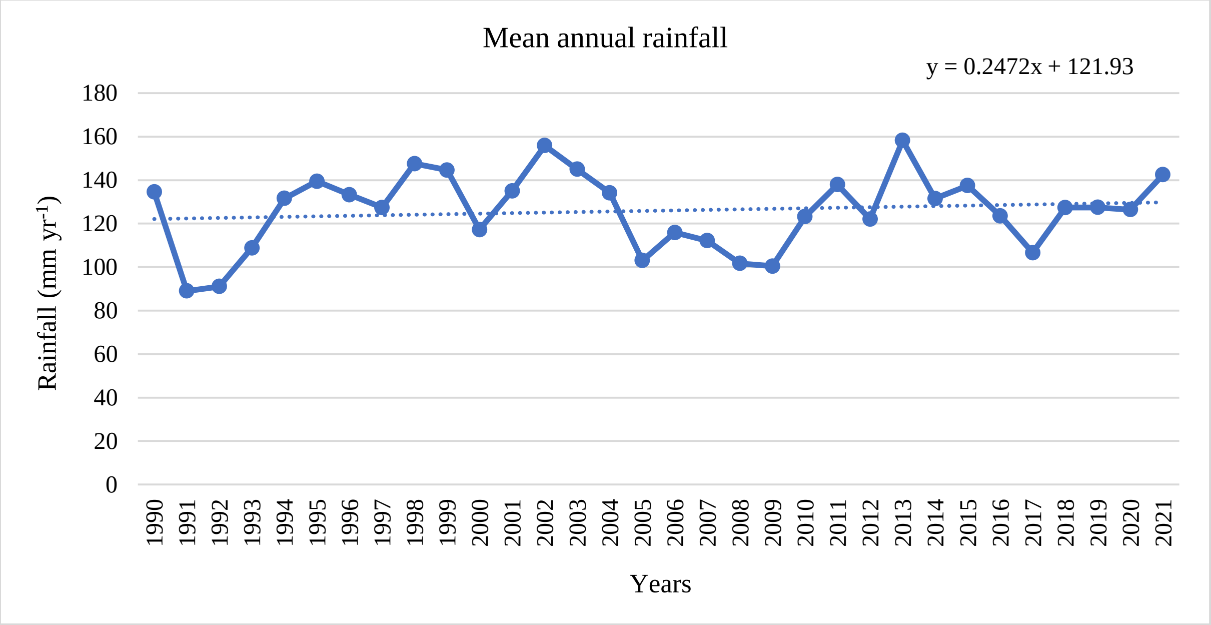

Figure 3: Annual mean rainfall of study station

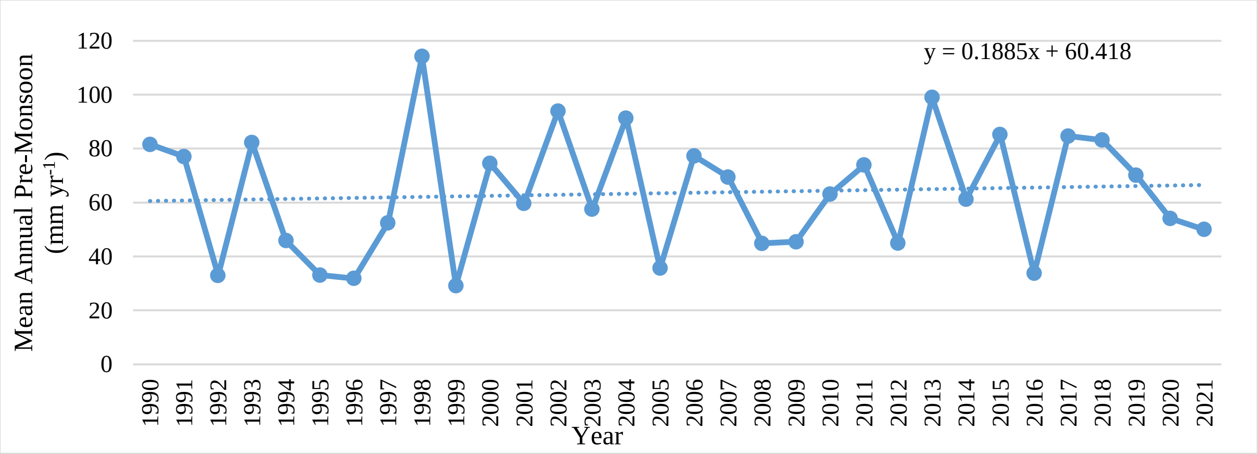

Figure 4: Mean annual pre monsoon

The mean monthly rainfall is increasing at the rate of 1.39 mm yr^{-1} (Figure 7). Here, maximum mean monthly rainfall is in the month of June and the minimum mean monthly rainfall is in the month of November. The maximum mean monthly rainfall in June is good for vegetative phase of paddy, as it requires enough water up to 550 mm during the phase. But, at the same time, less mean monthly rainfall in August and September creates poor availability of water for the reproductive phase of paddy. This directly disturbs the production capacity of rice.

Paddy Production and Rainfall Variability

Relationship between rainfall variability and paddy yield/productivity

Twenty-seven years of mean rainfall and paddy production from the month June to September was analyzed to compare the relationship between the two variables in the study area on the availability of production data (Figure 8). The meteorological information was accessed through the Department of Hydrology and Meteorology (DHM) and Agricultural data was accessed through the Ministry of Agriculture and Livestock Development (MoAD). The rainfall of pre monsoon, monsoon and post monsoon was studied as this has direct and indirect effect on paddy production in general.

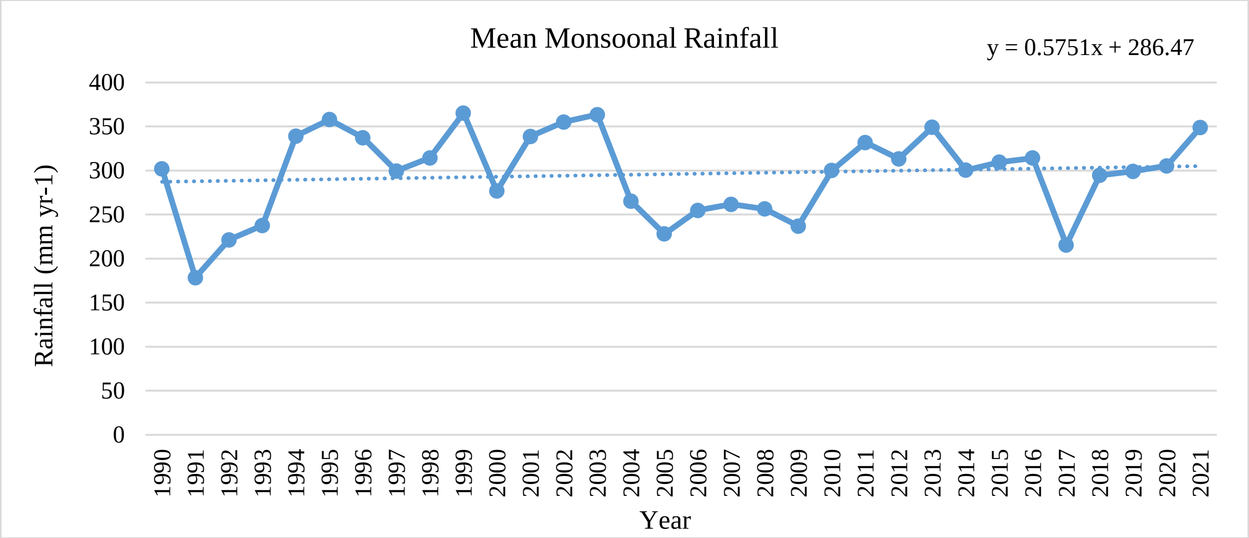

Figure 5: Mean annual monsoon

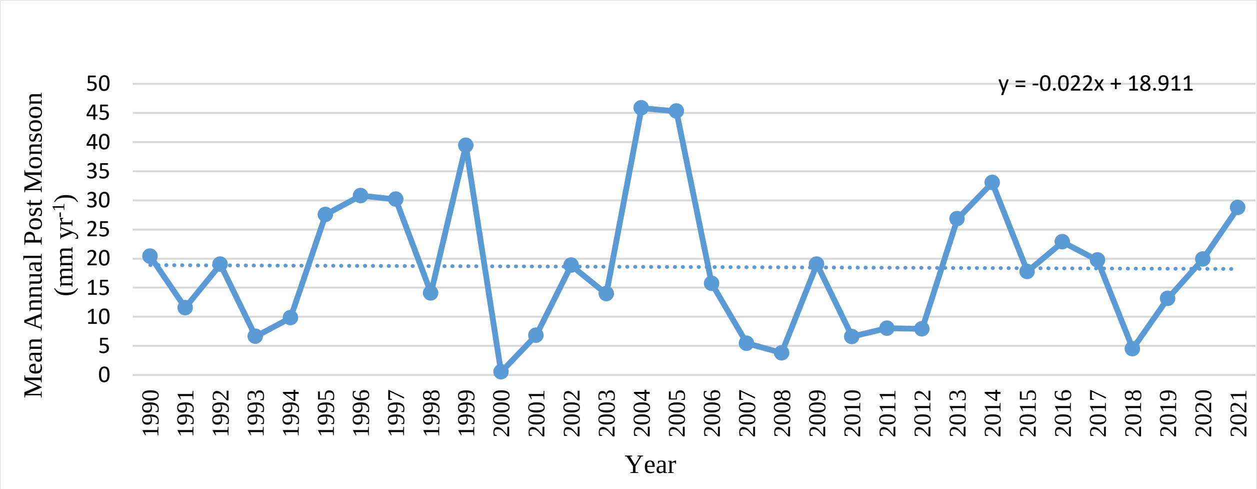

Figure 6: Mean annual post monsoon

The relationship between paddy production and the amount of mean rainfall was analyzed using Pearson's correlation coefficient. The rice production was positively correlated with the value 0.23 with the amount of rainfall in the study area (Table 1). It is clear that monsoon paddy yield does not seem to be too sensitive to the total rainfall during crop season. While large variation (900-1900 mm) in the rainfall is evident. The relationship between mean rainfall and paddy yield indicated that change in the monsoonal rainfall may affect the production of paddy in the study area i.e., increase in monsoonal rainfall increases the paddy yield. Since the value of 'r' is not so strong, this shows that paddy yield is not totally dependent on monsoon rainfall. Monsoonal rainfall is not only the primary factor to determine the productivity of rice in the study area. Even other factors, such as fertilizer and improved seeds are also the primary factors responsible for paddy yield in the study area.

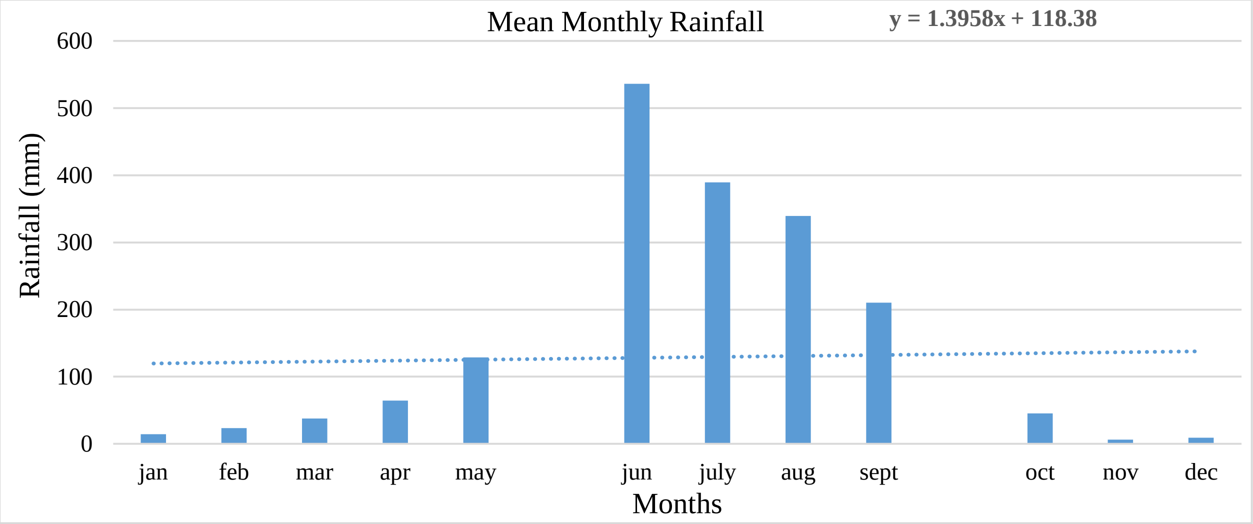

Figure 7: Mean monthly rainfall

Table 1: Correlation between paddy production and total annual rainfall

		Paddy production	*Total annual rainfall*
Paddy production	Pearson Correlation	1	.236
	Sig. (2-tailed)		.228
	N	28	28
Total annual rainfall	Pearson Correlation	.236	1
	Sig. (2-tailed)	.228	
	N	28	28

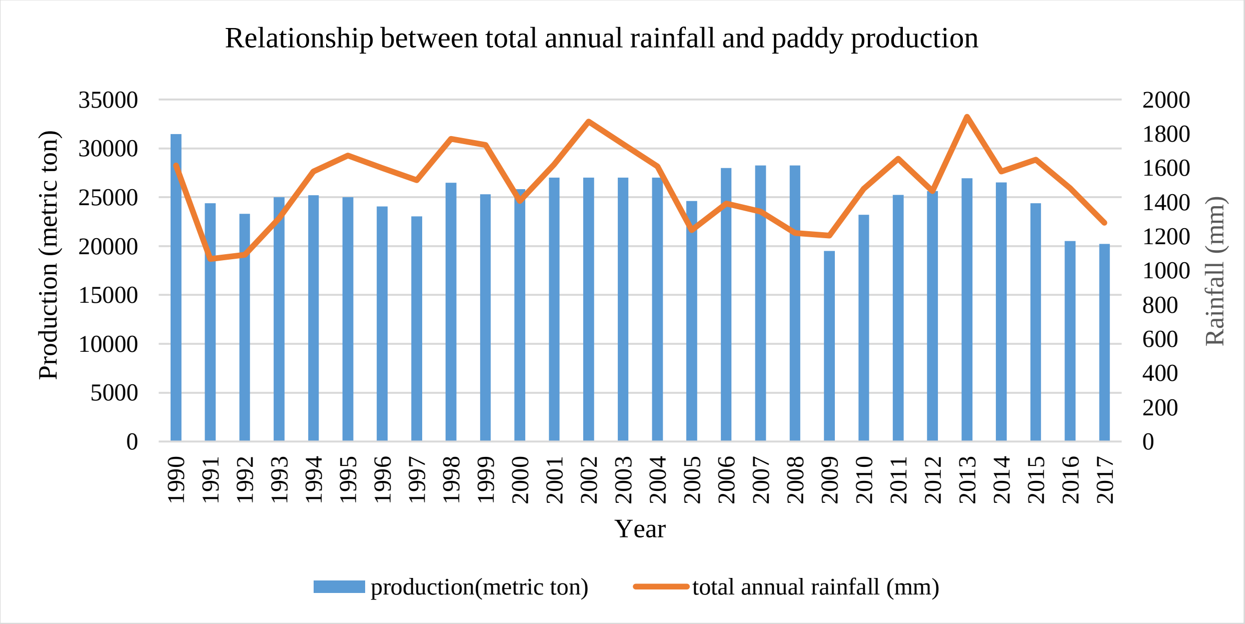

Figure 8: Relationship between total annual rainfall and paddy production

Paddy Production and Temperature Variability

Relationship between temperature variability and paddy production

Twenty-seven years of mean temperature and paddy production from the month June to September was analyzed to compare the relationship between these two variables in the study area on the availability of production data (Figure 9). The meteorological information was accessed through the Department of Hydrology and Meteorology (DHM) and the agricultural data was accessed through the Ministry of Agriculture and Livestock Development (MoAD). The temperature of pre-monsoon, monsoon and post-monsoon seasons was studied as this had direct and indirect effect on paddy production in general (Table 2).

The relationship between paddy production and the mean temperature was analyzed using Pearson's correlation coefficient. The rice production was negatively correlated with the value 0.15 with the annual mean temperature in the study area (Table 3). This correlation implies a negative impact on paddy production, if the mean annual temperature rises.

Table 2: Temperature requirement for paddy productivity at different growth stages

Stages of growth	Average temperature requirement (℃)
Vegetative stage	20℃-35℃
Reproductive stage	25℃-30℃
Ripening stage	20℃-30℃

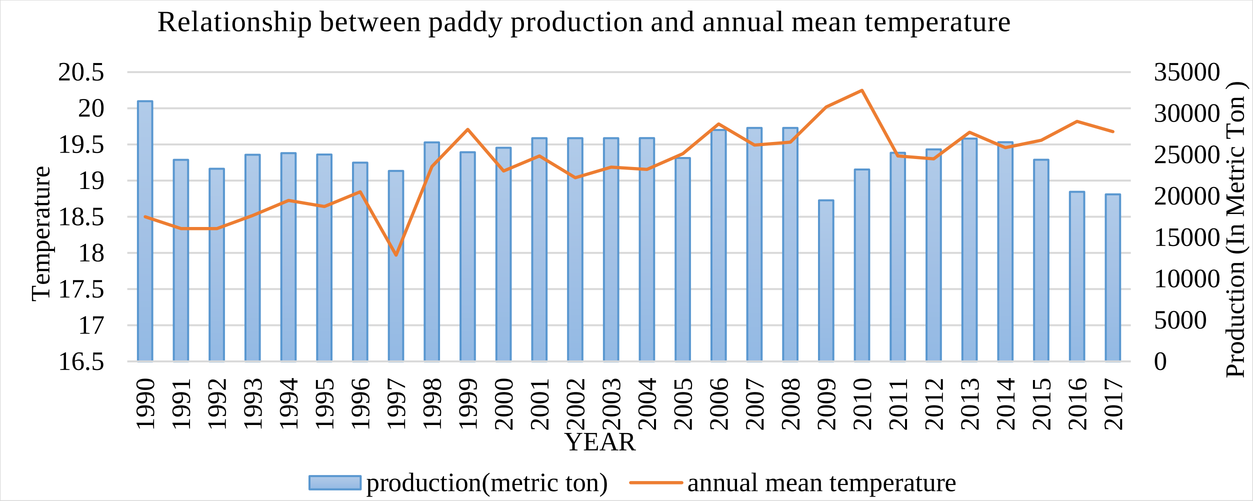

Figure 9: Relationship between annual mean temperature and paddy production

Table 3: Correlation between paddy production and annual mean temperature

		paddy production	annual mean temp
Paddy production	Pearson Correlation	1	-.159
	Sig. (2-tailed)		.418
	N	28	28
Annual mean temp	Pearson Correlation	-.159	1
	Sig. (2-tailed)	.418	
	N	28	28

People's Perception on Temperature, Rainfall and Other Factors

Temperature

The majority of the respondents have conveyed that summer temperature has increased. More than 70% of the respondents felt incremental change in temperature. They said that summer days are hotter and winter days lesser cold than before. About 77% of the respondents replied that they feel summer hotter than before and remaining 13% feel the same as it used to be earlier (Figure 10).

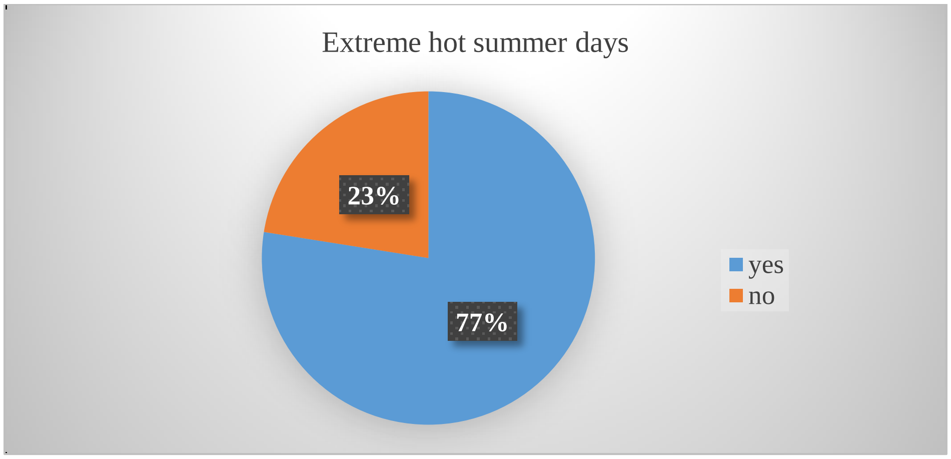

Figure 10: People perception about hot summer days

About 67% of the respondents gave positive responses that winter days are being less cold and frosty (Figure 11). The remaining 33% of the respondents do not feel any change regarding the winter temperature.

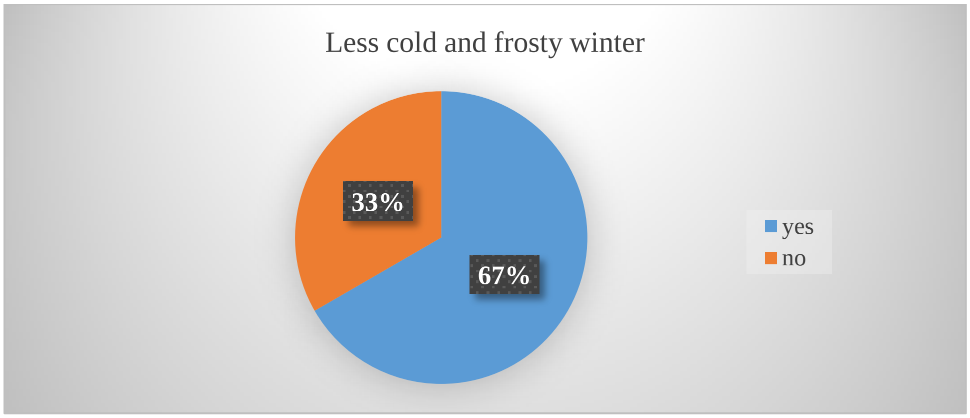

Figure 11: People perception about winter days

Rainfall

Most of the respondents experienced changed rainfall pattern and there is increased uncertainty of rainfall having direct impact on rain-fed agriculture. They responded trend of decreased rainfall in the areas these years (Figure 12). About 70% people felt decrease in duration of rainfall in the study area, and 26% of the respondents felt increase in duration of rainfall, whereas 4% of the respondents felt no change between before and now.

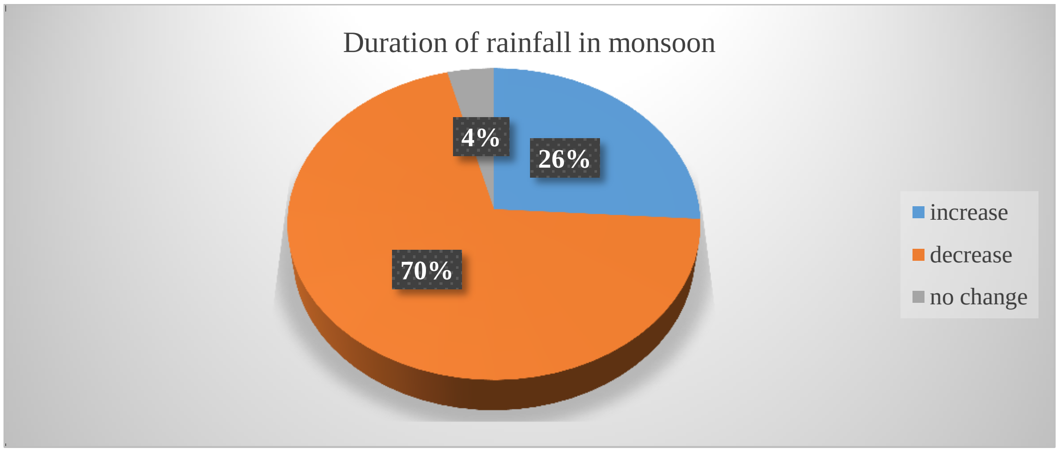

Figure 12: People perception on duration of rainfall

About 92% of the respondents responded that there is late starting of monsoon rainfall while rest 8% of the respondents responded that there is early/timely monsoon in the study area (Figure 13).

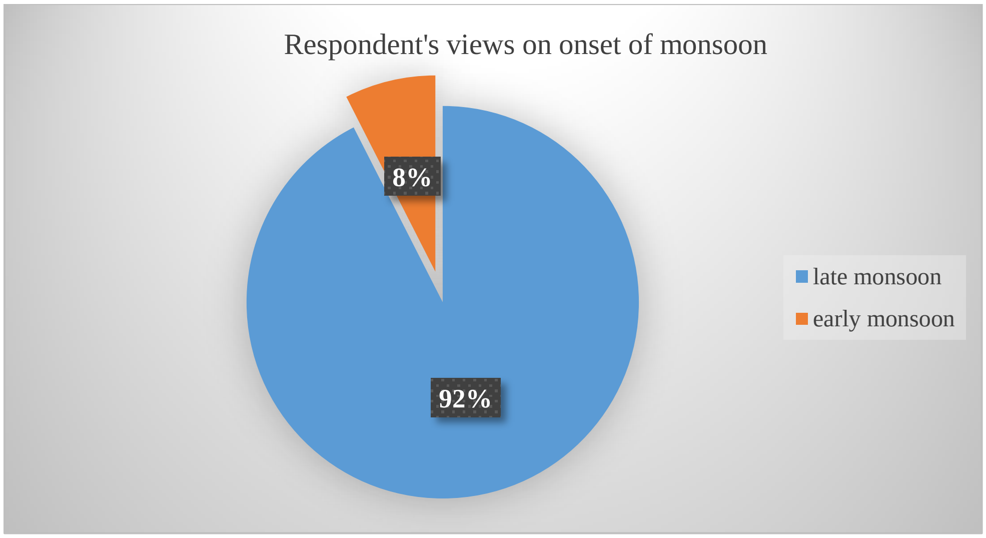

Figure 13: People perception on onset of monsoon

There is a shift of cropping date by one or two weeks. This is due to delay in monsoonal rainfall. Delay in monsoon date subsequently led to delay in harvesting time (Figure 14). Nearly 68% people replied to cropping date as second week of July and remaining 32% crop in third week of July. Likewise harvesting period also shifted forward. About 30% households harvested in September last week, 55% harvested in first week of October, and rest 15% harvested in second week of October. The timing of paddy plantation is found to be closely tuned to the rainfall variation.

Agricultural Impacts and Adaptation

The study area is mostly occupied by agricultural land with almost all households directly or indirectly involved in the agricultural practices. Climate factors like temperature and precipitation have direct impact on the agricultural production. Changes in the rainfall pattern, temperature, humidity have direct impacts on agricultural yield. The crop calendar was delayed so the starting time of cropping and its different stages and capacity seemed to be impacted due to the unusual changes in temperature and rainfall. Although the study area is facing changes in rainfall and temperature pattern, yet the paddy production is taking good height, except in some case. This is only due to the good adaptive measures adopted by the people. People use fertilizer regularly, especially organic fertilizer. The practices like change in crop variety, change in sowing plantation time are the effective adaptive measures taken by the people. The adaptive measures like change in crop variety, change in sowing plantation time is adopted by 33% and 22% people, respectively. Use of more fertilizer is the adaptive measure adopted by highest percentage of people, about 38% (Figure 15).

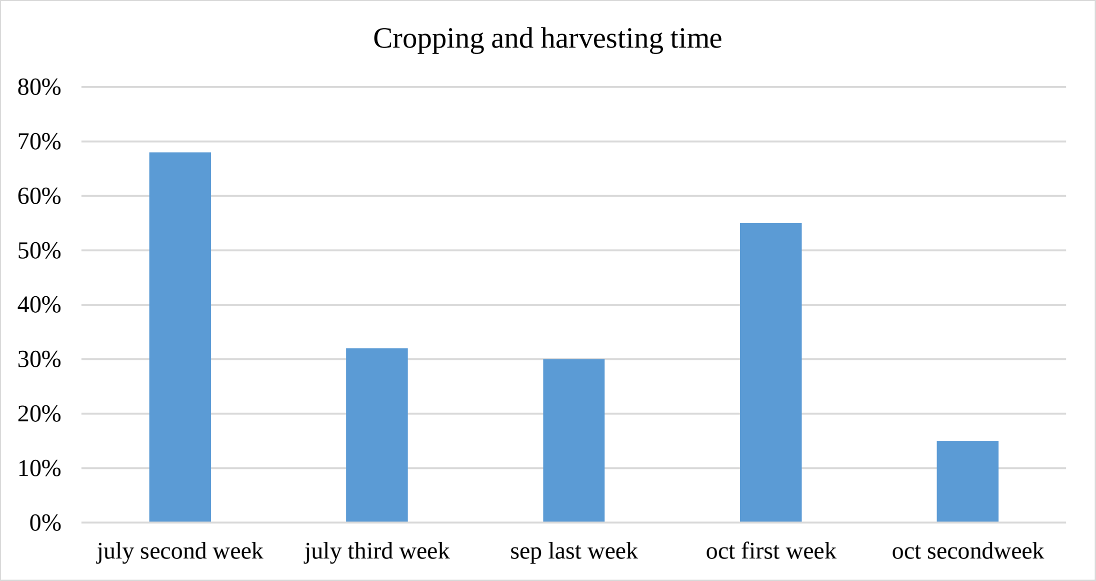

Figure 14: People perception on crop calendar

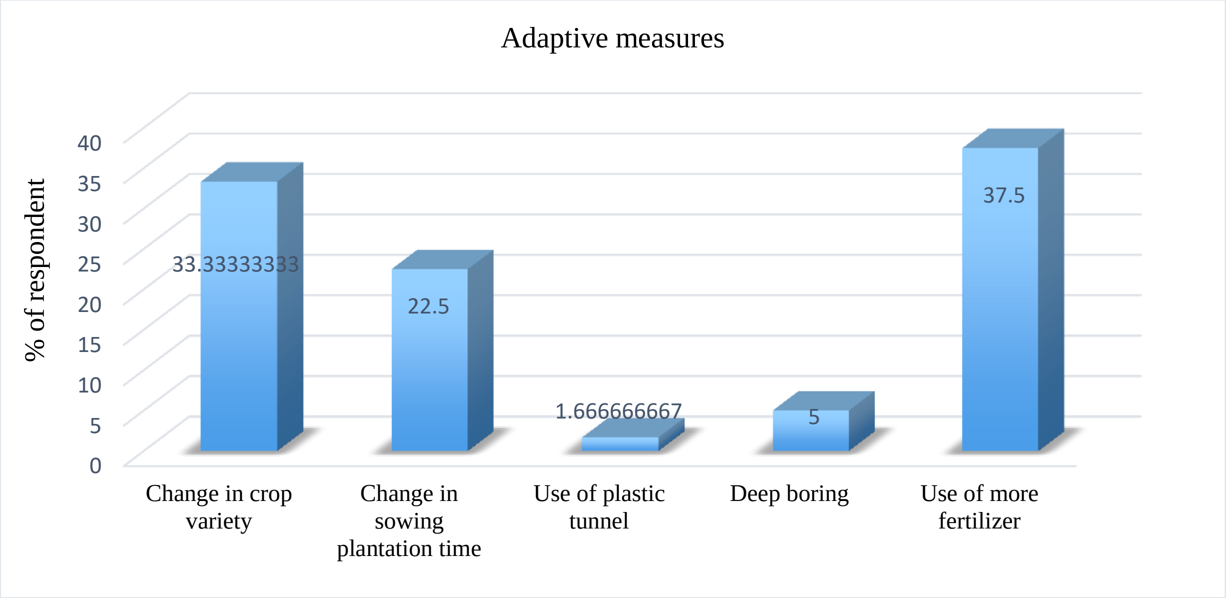

Figure 15: Percentage of Respondents saying "yes" to the Adaptive Measures

Discussion

The study on the impact of variation of monsoonal rainfall and temperature on yield of paddy crop is discussed in this section. Climate change and agriculture are closely linked and interdependent. Compared to conventional agriculture, organic farming is said to be more efficient and effective in reducing GHGs emission, mainly due to the less use of chemical fertilizers and fossil fuel. Organic farming is said to be climate change resilience farming systems, as it promotes the proper management of soil, water, biodiversity and local knowledge thereby acting as a good option for adaptation to climate change. It was found that most of the farmers grow rice during the monsoon season (June to September). Change in rainfall and temperature pattern can affect the paddy production. Paddy production in Bhaktapur district is in traditional system and do not fully dependent on the seasonal rainfall. The trend of annual precipitation in the study area is increasing at the rate of 0.24 mm yr^{-1}. The linear trend analysis of pre-monsoon shows that the rainfall is increasing at a rate of 0.18 mm yr^{-1} and the analysis of monsoon also shows that the rainfall is increasing at the rate of 0.57 mm yr^{-1}, whereas analysis of post-monsoon shows a decreasing rate of rainfall, i.e., 0.02 mm/year. The biggest changes in precipitation were observed during the monsoon season. The comparison between the linear trend analysis of precipitation and people's perception establishes that people do not agree with the increasing trend of monsoonal rainfall. 70% of the respondents felt that there is a decrease in duration of monsoonal rainfall; thus, it contradicts. This is because there has been a very erratic trend of monsoon precipitation ranging from 800 mm to just less than 1500 mm. This variation in monsoon rainfall is clearly unfavorable for the agriculture system in the study area. Thus, it is apparent that climate in the study area exhibits fluctuation over time, many of the changes are very erratic.

As per the data, all types of temperatures are being increased annually. The linear trend shows average annual temperature, minimum temperature, and maximum temperature being increased at the rate of 0.038℃ yr^{-1}, 0.054℃ yr^{-1} and 0.021℃ yr^{-1}, respectively. The average temperature was highest in the year 2010 with the value of 20.24℃. Strong signals of climate change were detected when the weather station data near Bhaktapur district was examined over the recent history (1990-2021). In 1996, minimum temperature seems to be decreased that indicated that there was cold winter. There was an increase in the maximum temperature indicating that the summer was too hot. Similarly, in 1997, both the maximum and minimum temperature decreased as a result of which the year seemed to have experienced cold. The comparison between the linear trend analysis of temperature and people's perception reveals increasing trend of temperature. The majority of the responses indicate the fact that summer temperature has increased. More than 70% of the respondents felt incremental change in temperature. They said that summer days are hotter and winter days have less cold than before. The data of 27 years of annual mean rainfall and paddy production were analyzed to compare the relationship between the two variables in the study area on the availability of production data. The relationship between paddy production and the quantum of mean annual rainfall was analyzed using Pearson's correlation coefficient. The rice production was positively correlated with the value 0.23 with the amount of rainfall in the study area. It is clear that monsoon paddy yield does not seem to be too sensitive to the total rainfall during crop season. This is because large variation (900–1900 mm) in the rainfall is evident. Since the value of 'r' is not so strong, this shows that paddy yield is not totally dependent on monsoon rainfall. Monsoonal rainfall is not the primary factor to determine the productivity of the study area. Even other factors, such as fertilizer and improved seeds are also the primary factors responsible for paddy yield in the study area as per the survey. In addition to this, the mean monthly rainfall is increasing at a rate of 1.39 mm/year. According to the findings, maximum mean monthly rainfall is in the month of June and the minimum mean monthly rainfall is in the month of November. The maximum mean monthly rainfall in June is good for vegetative phase of paddy as it requires enough water up to 550 mm during this phase. But, at the same time, less mean monthly rainfall in August and September creates poor availability of water for reproductive phase. This directly disturbs the production capacity of rice. Thus, this statement justifies the less value of 'r'.

Data of 27 years of annual mean temperature and paddy production was analyzed to compare the relationship between the two variables in the study area on the availability of production data. The relationship between paddy production and the annual mean temperature was analyzed using Pearson's correlation coefficient. The rice production was negatively correlated with the value 0.15 with the annual mean temperature in the study area. This correlation implies a negative impact on paddy production, if the mean annual temperature rises. The findings suggest a negative but statistically insignificant relationship between both minimum and maximum temperatures with paddy yields. This study notes that the current average maximum temperature for the decade of 1999 to 2008 is already 30.8°C. Thus, it is expected that rice yields are already being negatively affected by increases in the daily maximum temperature. Thus, these findings are similar to Devkota and Paija (2020).

Conclusion

This study investigated many aspects related to monsoonal rainfall and its changing pattern, change in maximum, minimum and average temperatures. The trend of annual precipitation in the study area is found to be increasing. Similarly, the linear trend analysis of pre-monsoon and monsoon shows the rainfall to be increasing at the rate of 0.18 mm yr^{-1} and 0.57 mm yr^{-1} respectively whereas post monsoon is found to be decreasing at the rate of 0.02 mm yr^{-1}. The biggest changes in precipitation were observed during the monsoon season. Likewise, the monsoon precipitation trend in the time series was found to be increasing. There has been a very erratic trend of monsoon precipitation ranging from around 800 mm to just below 1500 mm. This variation in monsoon rainfall is clearly unfavorable for the agriculture system of the study area. When these recent change in the temperature and precipitation was compared over 30-year time series data from the weather station, it is apparent that climate of study area exhibits fluctuation over time, many of the changes are very erratic. As per the data all kinds of temperature are being increased annually, the linear trend below shows average annual temperature, minimum temperature, and maximum temperature is found to be increasing at the rate of 0.038℃ yr^{-1}, 0.054℃ yr^{-1} and 0.021℃ yr^{-1}, respectively. People's perception on climate change is similar to trends of temperature and precipitation of nearby weather station. People have been facing several impacts on changes in temperature and rainfall. People of study area are facing several impacts like change in seasonal calendar, decrease in crop production, change in cropping patterns and agricultural practices, increase in pests and diseases. It can be visualized that shifting in the crop calendar by one or two week later and use of fertilizer and improved seeds effectively by almost all farmers. People of Bhaktapur district are more dependent on rainfall. Irregular/untimely rainfall damages the crop varieties. Adaptation like rainwater harvesting, formation of plastic ponds was not seen in the area. This study therefore recommends shifting of crop plantation date, temperature resilient crop genotype (to overcome temperature stress), and proper water and fertilizer management to stabilize the crop yield. There is the urgent need of formulation and implementation of better adaptation strategy, plans and policies.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

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Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	No
Critical revision of the article/paper	No	Yes
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